EXHIBIT A

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Terra Money:

Stability and Adoption

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Abstract

While many see the benefits of a price-stable cryptocurrency that combines the best of both fiat and Bitcoin, not many have a clear plan for the adoption of such a currency. Since the value of a currency as a medium of exchange is mainly driven by its network effects, a successful new digital currency needs to maximize adoption in order to become useful. We propose a cryptocurrency, Terra, which is both price-stable and growth-driven. It achieves price-stability via an elastic money supply, enabled by stable mining incentives. It also uses seigniorage created by its minting operations as transaction stimulus, thereby facilitating adoption. There is demand for a decentralized, price-stable money protocol in both fiat and blockchain economies. If such a protocol succeeds, then it will have a significant impact as the best use case for cryptocurrencies.

1 Introduction

The price-volatility of cryptocurrencies is a well-studied problem by both academics and market observers (see for instance, Liu and Tsyvinski, 2018, Makarov and Schoar, 2018). Most cryptocurrencies, including Bitcoin, have a predetermined issuance schedule that, together with a strong speculative demand, contributes to wild fluctuations in price. Bitcoin's extreme price volatility is a major roadblock towards its adoption as a medium of exchange or store of value. Intuitively, nobody wants to pay with a currency that has the potential to double in value in a few days, or wants to be paid in a currency if its value can significantly decline before the transaction is settled. The problems are aggravated when the transaction requires more time, e.g. for deferred payments such as mortgages or employment contracts, as volatility would severely disadvantage one side of the contract, making the usage of existing digital currencies in these settings prohibitively expensive.

At the core of how the Terra Protocol solves these issues is the idea that a cryptocurrency with an elastic monetary policy would maintain a stable price, retaining all the censorship resistance of Bitcoin, and making it viable for use in everyday transactions. However, price-stability is not sufficient for the wide adoption of a currency. Currencies inherently have strong network effects: a customer is unlikely to switch over to a new currency unless a critical mass of merchants are ready to accept it, but at the same time, merchants have no reason to invest resources and educate staff to accept a new currency unless there is significant customer demand for it. For this reason, Bitcoin's adoption in the payments space has been limited to small businesses whose owners are personally invested in cryptocurrencies. Our belief is that while an elastic monetary policy is the solution to the stability problem, an efficient fiscal policy can drive adoption. In addition, the Terra Protocol offers strong incentives for users to join the network with an efficient fiscal spending regime, managed by a Treasury, where multiple stimulus programs compete for financing. That is, proposals from community participants will be vetted by the rest of the ecosystem and, when approved, they will be financed with the objective to increase adoption and expand the potential use cases. The Terra Protocol with its balance between fostering stability and adoption represents a meaningful complement to fiat currencies as a means of payment and store of value.

The rest of the paper is organized as follows. We first discuss the protocol and how stability is achieved and maintained, through the calibration of miners' demand and the use of the native

mining Luna token. We then dig deeper into how stable mining incentives are adopted to smooth out economic fluctuations. Lastly, we discuss how Terra's fiscal policy can be used as an efficient stimulus to drive adoption.

2 Multi-fiat peg monetary policy

A stable-coin mechanism must answer three key questions:

- **How is price-stability defined?** Stability is a relative concept; which asset should a stable-coin be pegged to in order to appeal to the broadest possible audience?
- **How is price-stability measured?** Coin price is exogenous to the Terra blockchain, and an efficient, corruption-resistant price feed is necessary for the system to function properly.
- **How is price-stability achieved?** When coin price has deviated from the target, the system needs a way to apply pressures to the market to bring price back to the target.

This section will specify Terra's answers to the above questions in detail.

2.1 Defining stability against regional fiat currencies

The existential objective of a stable-coin is to retain its purchasing power. Given that most goods and services are consumed domestically, it is important to create crypto-currencies that track the value of local fiat currencies. Though the US Dollar dominates international trade and forex operations, to the average consumer the dollar exhibits unacceptable volatility against their choice unit of account.

Recognizing strong regionalities in money, Terra aims to be a family of cryptocurrencies that are each pegged to the world's major currencies. Close to genesis, the protocol will issue Terra currencies pegged to USD, EUR, CNY, JPY, GBP, KRW, and the IMF SDR. Over time, more currencies will be added to the list by user voting. TerraSDR will be the flagship currency of this family, given that it exhibits the lowest volatility against any one fiat currency (Kereiakes, 2018). TerraSDR is the currency in which transaction fees, miner rewards and stimulus grants will be denominated.

It is important, however, for Terra currencies to have access to shared liquidity. For this reason, the system supports atomic swaps among Terra currencies at their market exchange rates. A

user can swap TerraKRW for TerraUSD instantly at the effective KRW/USD exchange rate. This allows all Terra currencies to share liquidity and macroeconomic fluctuations; a fall in demand by one currency can quickly be absorbed by the others. We can therefore reason about the stability of Terra currencies in a group; we will be referring to Terra loosely as a single currency for the remainder of this paper. As Terra's ecosystem adds more currencies, its atomic swap functionality can be an instant solution to cross border transactions and international trade settlements.

2.2 Measuring stability with miner oracles

Since the price of Terra currencies in secondary markets is exogenous to the blockchain, the system must rely on a decentralized price oracle to estimate the true exchange rate. We define the mechanism for the price oracle as the following:

- For any Terra sub-currency in the set of currencies C = TerraKRW, TerraUSD, TerraSDR... miners submit a vote for what they believe to be the current exchange rate in the target fiat asset.
- Every n blocks the vote is tallied by taking the weighted medians as the true rates.
- Some amount of Terra is rewarded to those who voted within 1 standard deviation of the elected median. Those who voted outside may be punished via slashing of their stakes. The ratio of those that are punished and rewarded may be calibrated by the system every vote to ensure that a sufficiently large portion of the miners vote.

Several issues have been raised in implementing decentralized oracles, but chief among them is the possibility for voters to profit by coordinating on a false price vote. Limiting the vote to a specific subset of users with strong vested interest in the system, the miners, can vastly decrease the odds of such a coordination. A successful coordination event on the price oracle would result in a much higher loss in the value of the miner stakes than any potential gains, as Luna stakes are time-locked to the system.

The oracle can also play a role in adding and deprecating Terra currencies. The protocol may start supporting a new Terra currency when oracle votes for it satisfies a submission threshold. Similarly, the failure to receive a sufficient number of oracle votes for several periods could trigger the deprecation of a Terra currency.

2.3 Achieving stability with consistent mining rewards

Once the system has detected that the price of a Terra currency has deviated from its peg, it must apply pressures to normalize the price. Like any other market, the Terra money market follows the simple rules of supply and demand for a pegged currency. That is:

- Contracting money supply, all conditions held equal, will result in higher relative currency price levels. That is, when price levels are falling below the target, reducing money supply sufficiently will return price levels to normalcy.
- Expanding money supply, all conditions held equal, will result in lower relative currency price levels. That is, when price levels are rising above the target, increasing money supply sufficiently will return price levels to normalcy.

Of course, contracting the supply of money isn't free; like any other asset, money needs to be bought from the market. Central banks and governments shoulder contractionary costs for pegged fiat systems through a variety of mechanisms including intervention, the issuance of bonds and short-term instruments thus incurring interest expenses, and hiking of money market rates and reserve ratio requirements thus losing revenue. Put in a different way, central banks and governments absorb the volatility of the pegged currencies they issue.

Analogously, Terra miners absorb volatility in Terra supply.

- **In the short term, miners absorb Terra contraction costs** through mining power dilution. During a contraction, the system mints and auctions more mining power to buy back and burn Terra. This contracts the supply of Terra until its price has returned to the peg, and temporarily results in mining power dilution.
- **In the mid to long term, miners are compensated with increased mining rewards**. First, the system continues to buy back mining power until a fixed target supply is reached, thereby creating long-run dependability on available mining power. Second, the system increases mining rewards, which will be explained in more detail in a later section.

In summary, miners bear the costs of Terra volatility in the short term, while being compensated for it in the long-term. Compared to ordinary users, miners have a long-term vested interest in

the stability of the system, with invested infrastructure, trained staff and business models with high switching cost. The remainder of this section will discuss how the system absorbs short-term volatility and creates stable long-term incentives for Terra miners.

2.4 Miners absorb short-term Terra volatility

The Terra Protocol runs on a Proof of Stake (PoS) blockchain, where miners need to stake a native cryptocurrency Luna to mine Terra transactions. At every block period, the protocol elects a block producer from the set of staked miners, which is entrusted with the work required to produce the next block by aggregating transactions, achieving consensus among miners, and ensuring that messages are distributed properly in a short timeframe with high fault tolerance.

The block producer election is weighted by the size of the active miner's Luna stake. Therefore, **Luna represents mining power in the Terra network.** Similar to how a Bitcoin miner's hash power represents a pro-rata odds of generating Bitcoin blocks, the Luna stake represents pro-rata odds of generating Terra blocks.

Luna also serves as the most immediate defense against Terra price fluctuations. The system uses Luna to make the price for Terra by agreeing to be counter-party to anyone looking to swap Terra and Luna at Terra's target exchange rate. More concretely:

- When TerraSDR's price $<$ 1 SDR, users and arbitragers can send 1 TerraSDR to the system and receive 1 SDR's worth of Luna.
- When TerraSDR's price $>$ 1 SDR, users and arbitragers can send 1 SDR's worth of Luna to the system and receive 1 TerraSDR.

The system's willingness to respect the target exchange rate irrespective of market conditions keeps the market exchange rate of Terra at a tight band around the target exchange rate. An arbitrageur can extract risk-free profit when 1 TerraSDR $=$ 0.9 SDR by trading TerraSDR for 1 SDR's worth of Luna from the system, as opposed to 0.9 SDR's worth of assets she could get from the open market. Similarly, she can also extract risk-free profit when 1 TerraSDR $=$ 1.1 SDR by trading in 1 SDR worth of Luna to the system to get 1.1 SDR worth of TerraSDR, once again beating the price of the open market.

The system finances Terra price making via Luna:

- To buy 1 TerraSDR, the protocol mints and sells Luna worth 1 SDR
- By selling 1 TerraSDR, the protocol earns Luna worth 1 SDR

As Luna is minted to match Terra offers, volatility is moved from Terra price to Luna supply. If unmitigated, this Luna dilution presents a problem for miners; their Luna stakes are worth a smaller portion of total available mining power post-contraction. The system burns a portion of the Luna it has earned during expansions until Luna supply has reached its 1 billion equilibrium issuance. Therefore, Luna can have steady demand as a token with pro-rata rights to Terra mining over the long term. The next section discusses how the system offers stable mining incentives to keep the market for mining and demand for Luna long-term stable through volatile macroeconomic cycles.

2.5 Miners are compensated with long-term stable rewards

Miners play a foundational role in the security and stability of Terra. They provide the former by participating in PoS consensus. They provide the latter by absorbing short-term volatility in Terra demand. **Stable demand for mining is a core requirement for both security and stability.** To achieve this, the protocol aims to offer stable and predictable rewards in all economic conditions, booms and busts alike. The network is best off when it can consistently compensate those that protect it.

The protocol has two ways of rewarding miners for their work:

- **Transaction fees**: All Terra transactions pay a small fee to miners. Fees default to 0.1% and are capped at 1%, meaning that transacting with Terra in e-commerce will be much cheaper than transacting with traditional payment options such as credit cards[1].
- **Seigniorage (Luna burn)**: When demand for Terra increases, the system mints Terra and earns Luna in return. This is called seigniorage — the value of newly minted currency minus the cost of issuance (which in this case is zero). The system burns a portion of earned Luna, which makes mining power scarcer. The remaining portion of seigniorage goes to the Treasury to fund fiscal stimulus.

To understand rewards from the perspective of a miner, we look at the basic calculus one has to go through to determine the viability of a long-term commitment to mining on the Terra network.

[1]The fee per transaction is capped at 1SDR (1.39 USD at the time of writing), meaning that larger transactions also pay considerably less than traditional wire transfers

After fixed costs, the profit (or loss) from a mining operation for a single unit of mining power (1 Luna) comes down to rewards minus cost of work for that unit. A bit more formally, during a future work period t, profit or loss for a unit of mining power equals

$$P(t) = \frac{TotalRewards(t)}{LunaSupply(t)} - UnitMiningCost(t)$$

Frequent alternations between profit and loss – positive and negative $P(t)$ – would create highly unstable mining demand. The goal of the protocol is to make this calculus easier and more predictable. With that in mind, most of the uncertainty in $P(t)$ comes down to the first term, ie *unit mining rewards*. As a consequence, unit mining rewards are the primary consideration for making a long-term commitment to the network. Stable unit mining rewards produce stable demand for mining, while volatile unit mining rewards produce the opposite.

By default, there is uncertainty both in total rewards (from fees) and in the supply of Luna, so both terms contribute to the volatility in unit rewards. First, rewards from fees tend to increase when the economy grows and tend to decrease when the economy shrinks. Second, Luna supply tends to decrease when the economy grows (because Luna is burned from seigniorage), and it tends to increase when the economy shrinks (because new Luna is issued to buy back Terra). The implication is that unit mining rewards have a tendency to move strongly in the direction of the economy, either up or down. By extention this also applies to mining demand.

So in order to create mining demand that is long-term stable, **the protocol creates predictable rewards in all economic conditions.** To achieve this, the protocol uses transaction fees and the rate of Luna burn as levers to *oppose* changes in unit mining rewards. Transaction fees affect total rewards, while the rate of Luna burn affects Luna supply – the two determinants of *unit* mining rewards. The basic logic is the following:

- if unit mining rewards are *increasing*:
  - *decrease* fees
  - *decrease* Luna burn
- if unit mining rewards are *decreasing*:
  - *increase* fees

– *increase* Luna burn

While working to smooth out fluctuations in miner compensation, the protocol also targets stable growth in line with the long-term growth of the Terra economy. This is a natural reward for their long-term commitment to serving the network.

To formalize those ideas, we discuss the mechanism to smooth out unit mining rewards in more detail [2]. Fees and the rate of Luna burn – the "stability levers" – are adjusted every week in response to changes in unit mining rewards. We define the rate of Luna burn as follows: what portion (%) of seigniorage does the protocol use to buy back and burn Luna, as opposed to depositing to the Treasury? Let f_t, b_t and R_t be transaction fees, the rate of Luna burn and *unit* mining rewards at time t respectively. Then the rule for adjusting the values of f and b is the following:

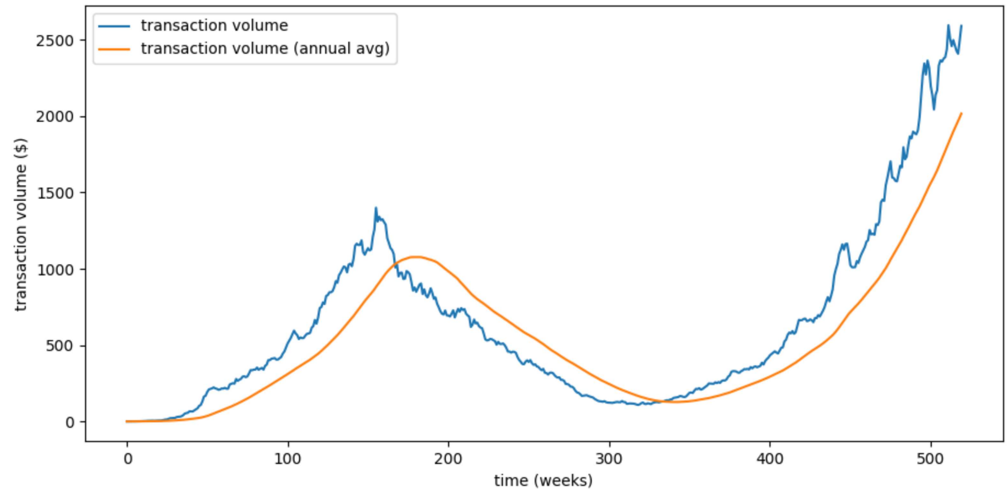
$$f_{t+1} = (1+g) \cdot \frac{R_{t-1}}{R_t} \cdot f_t$$

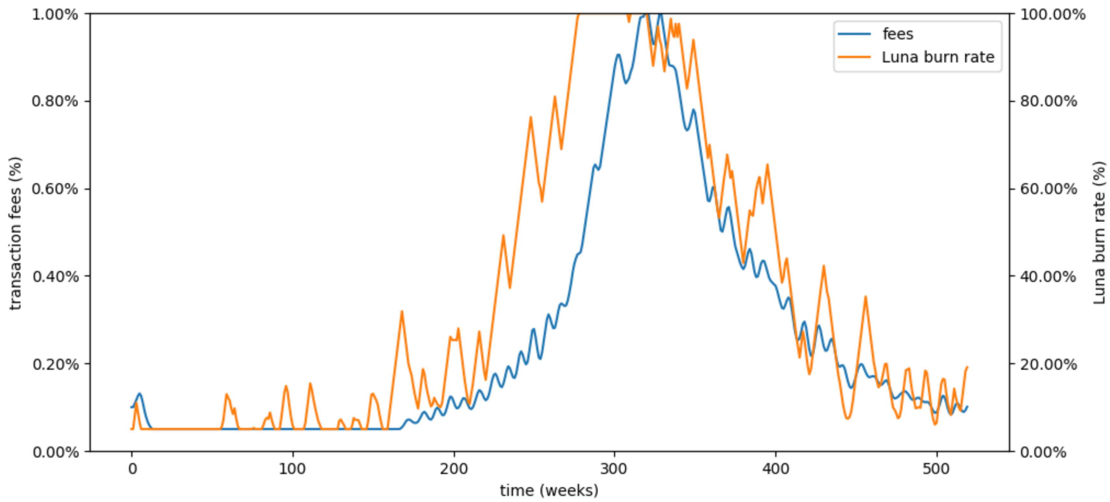
$$b_{t+1} = (1+g) \cdot \frac{R_{t-1}}{R_t} \cdot b_t$$

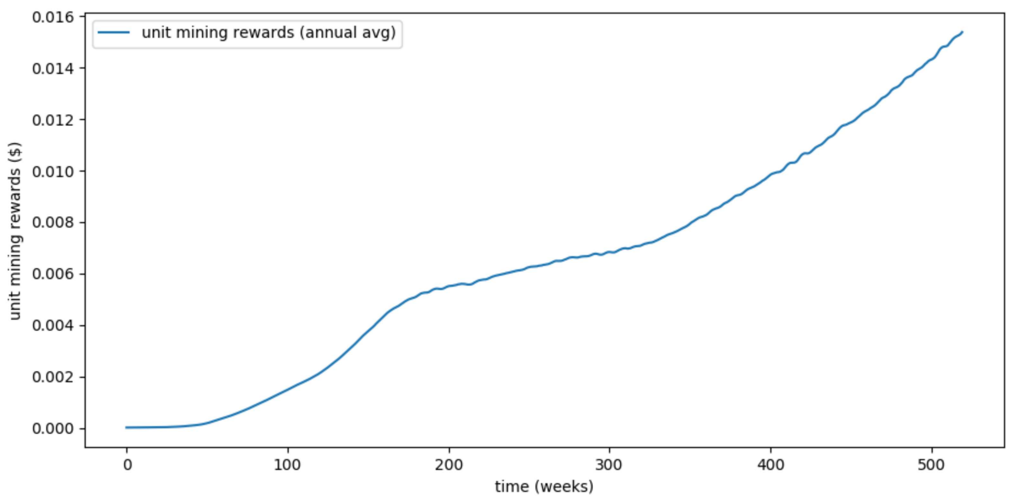
The update rules should now make clear what we mean when we say that fees (and Luna burn rate) *oppose* changes in unit mining rewards: the current value, f_t, is multiplied by the *inverse change* in unit mining rewards, $\frac{R_{t-1}}{R_t}$. For example, if unit mining rewards were cut in half then fees would double in response, and conversely if unit mining rewards were to double fees would be cut in half in response. The result is scaled by a small growth factor, $1+g$, that permits gradual growth in unit mining rewards commensurate with the *long-term* growth rate of the economy.

How well does the mechanism work in practice? We have run extensive simulations to stress-test and refine it under a breadth of assumptions. In what follows we share and discuss a representative example that applies significant stress to the mechanism and sheds light on how it achieves its objective. We consider a simulated 10 year period during which the Terra economy experiences both rapid growth and severe turbulence. We demonstrate how the protocol adjusts its stability levers in response to economic conditions, and how those adjustments in turn shape unit mining rewards.

[2]The mechanism we present is slightly simplified. We omit a few details, eg the protocol uses moving averages in mining rewards for robustness and ensures consistent contribution of buybacks relative to fees in all situations.


transaction volume
transaction volume (annual avg)
transaction volume ($)
2500
2000
1500
1000
500
0
0
100
200
300
400
500
time (weeks)


fees
Luna burn rate
transaction fees (%)
1.00%
0.80%
0.60%
0.40%
0.20%
0.00%
Luna burn rate (%)
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
0
100
200
300
400
500
time (weeks)


unit mining rewards (annual avg)
unit mining rewards ($)
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0
100
200
300
400
500
time (weeks)

The first graph shows simulated weekly **transaction volume** and its annual moving average. Transaction volume can be thought of as the GDP of the Terra economy. The economy experiences rapid growth followed by a severe multi-year recession that wipes out 93% of GDP over 3 years and requires 6 years for full recovery. This scenario is a stern test – if it were describing the price of Bitcoin it would be by far the longest bear market in its history and tied for worst in terms of drawdown (equal to the 93% drop between June and November 2011). While we think that Terra's adoption-driven demand will be far more stable than Bitcoin's speculation-driven demand, the stability mechanism has been designed to confidently withstand Bitcoin-level volatility.

The second graph shows **transaction fees and the Luna burn rate**, the two levers used by the protocol to smooth out fluctuations in unit mining rewards. We observe that both move *opposite* to the direction of the economy (which is also the default direction of unit mining rewards).

The third graph shows the annual moving average of **unit mining rewards.** The growth target we have set in this example is 15% annually. As was designed, unit mining rewards experience steady growth with low volatility, unpurturbed by the cycles in Terra's GDP. The adjustments in fees and the Luna burn rate have successfully absorbed the expected volatility in unit mining rewards and created predictable growth. This is achieved with fees that average less than 0.5% (with a momentary peak at the 1% maximum) and a Luna burn rate that averages roughly 50% (meaning that on average 50% of seigniorage is granted to the Treasury).

Stable demand for mining is a core requirement for the security and stability of Terra. Unit mining rewards are the primary consideration and the biggest source of risk for miners. They are by default highly cyclical, hence highly uncertain. Reducing that uncertainty in the face of volatile conditions is the key to stable mining demand. We have outlined a simple mechanism that uses transaction fees and Luna burn as levers to achieve this, and demonstrated its effectiveness in the most severe economic conditions.

3 Growth-driven fiscal policy

Despite their enormous potential, smart contracts have faced roadblocks in adoption due to the price volatility of their underlying currency. Price volatility makes smart contracts unusable for most mainstream financial applications, as most users are accustomed to valuing determinate payouts in insurance, credit, mortgage, and payroll. Terra will offer a stable dApp platform oriented to building

financial applications that use Terra as their underlying currency, thus allowing smart contracts to mature into a useful infrastructure for mainstream businesses. Terra Platform DApps will help to drive growth and stabilize the Terra family of currencies by diversifying its use cases. In this section we discuss how the protocol subsidizes the growth of the more successful applications through its growth-driven fiscal policy.

National governments use expansionary fiscal spending with the objective of stimulating growth. The hope of fiscal spending is that the economic activity instigated by the original spending results in a feedback loop that grows the economy more than the amount of money spent in the initial stimulus. This concept is captured by the spending multiplier — how many dollars of economic activity does one dollar of fiscal spending generate? The spending multiplier increases with the marginal propensity to consume, meaning that the effectiveness of the expansionary stimulus is directly related to how likely economic agents are to increase their spending.

In a previous section, we discussed how Terra seigniorage is directed to both miner rewards and the Treasury. At this point, it is worth describing how exactly the Treasury implements Terra's fiscal spending policy, with its core mandate being to stimulate Terra's growth while ensuring its stability. In this manner, Terra achieves greater efficiency by returning seigniorage not allocated for stability back to its users.

The Treasury's main focus is the allocation of resources derived from seigniorage to decentralized applications (dApp). To receive seigniorage from the Treasury, a dApp needs to register for consideration as an entity that operates on the Terra network. dApps are eligible for funding depending on their economic activity and use of funding.

The funding procedure for a dApp works as follows:

- A dApp applies for an account with the Treasury; the application includes metadata such as the Title, a url leading to a detailed page regarding the use of funding, the wallet address of the applicant, as well as auditing and governance procedures.

- At regular voting intervals, Luna validators vote to accept or reject new dApp applications for Treasury accounts. The net number of votes (yes votes minus no votes) needs to exceed 1/3 of total available validator power for an application to be accepted.

- Luna validators can exercise control over which dApps may open accounts with the Treasury.

The funding itself is determined by validator voting for each funding period in accordance with a weight that is assigned to each dApp. This allows the Treasury to prioritize dApps that earn the most funding.

- At each voting session, Luna validators have the right to request that a dApp be blacklisted, for example because it behaves dishonestly or fails to account for its use of Treasury funds. Again, the net number of votes (yes votes minus no votes) needs to exceed 1/3 of total available validator power for the blacklist to be enforced. A blacklisted dApp loses access to its Treasury account and is no longer eligible for funding.

The motivation behind assigning funding weights to dApps is to maximize the impact of the stimulus on the economy by rewarding the dApps that are more likely to have a positive effect on the economy. The Treasury uses two criteria to determine spending allocations: (1) **robust economic activity** and (2) **efficient use of funding**. dApps with a strong track record of adoption receive support for their continued success, and dApps that have grown relative to their funding are rewarded with more seigniorage, as they have a successful track record of efficiently using their resources.

Those two criteria are combined into a single weight which determines the relative funding that dApps receive from the aggregate funding pool. For instance, a dApp with a weight of 2 would receive twice the amount of funding of a dApp with a weight of 1.

We lay out the funding weight equation, followed by a detailed explanation of all the parts: For a time period t, let TV_t be a dApp's transaction volume and F_t be the Treasury funding received. Then, the protocol determines the funding weight w_t for the period as follows:

$$w_t = (1 - \lambda)\, TV_t^* + \lambda \frac{\Delta TV_t^*}{F_{t-1}^*}$$

The notation * denotes a moving average, so TV_t^* would be the moving average of transaction volume leading up to time period t, while ΔTV_t^* would be a difference of moving averages of different lengths leading up to time period t. One might make the averaging window quarterly for example. Finally, the funding weights among all dApps are scaled to sum to 1.

- **The first term** is proportional to TV_t^*, the average transaction volume generated by the dApp in the recent past. This is an indicator of the dApp's **economic activity**, or more

simply the size of its micro-economy.

- **The second term** is proportional to $\Delta TV *_t / F *_t -1$. The numerator describes the trend in transaction volume — it is the difference between a more and a less recent average. When positive, it means that the transaction volume is following an upward trajectory and vice versa. The denominator is the average funding amount received by the dApp in the recent past, up to and including the previous period. So the second term describes how economic activity is changing relative to past funding. Overall, larger values of this ratio capture instances where the dApp is fast-growing for each dollar of funding it has received. This is in fact the spending multiplier of the funding program, a prime indicator of **funding efficiency**.

- The parameter λ is used to determine the relative importance of economic activity and funding efficiency. If it is set equal to 1/2 then the two terms would have equal contribution. By decreasing the value of λ, the protocol can favor more heavily dApps with larger economies. Conversely, by increasing the value of λ the protocol can favor dApps that are using funding with high efficiency, for example by growing fast with little funding, even if they are smaller in size.

An important advantage of distributing funding in a programmatic way is that it is simpler, objective, transparent and streamlined compared to open-ended voting systems. In fact, compared to decentralized voting systems, it is more predictable, because the inputs used to compute the funding weights are transparent and slow moving. Furthermore, this system requires less trust in Luna validators, given that the only authority they are vested with is determining whether or not a dApp is honest and makes legitimate use of funding.

Overall, the objective of Terra governance is simple: fund the organizations and proposals with the highest net impact on the economy. This will include dApps solving real problems for users, increasing Terra's adoption and as a result increasing the GDP of the Terra economy.

4 Conclusion

We have presented Terra, a stable digital currency that is designed to complement both existing fiat and cryptocurrencies as a way to transact and store value. The protocol adjusts the supply of Terra in response to changes in demand to keep its price stable. This is achieved using Luna, the

mining token whose stable rewards are designed to absorb volatility from changing economic cycles. Terra also achieves efficient adoption by returning seigniorage not invested in stability back to its users. Its transparent and democratic distribution mechanism gives dApps the power to attract and retain users by tapping into Terra's economic growth.

If Bitcoin's contribution to cryptocurrency was immutability, and Ethereum expressivity, our value-add will be usability. The potential applications of Terra are immense. Immediately, we foresee Terra being used as a medium-of-exchange in online payments, allowing people to transact freely at a fraction of the fees charged by other payment methods. As the world starts to become more and more decentralized, we see Terra being used as a dApp platform where price-stable token economies are built on Terra. Terra is looking to become the first usable currency and stability platform on the blockchain, unlocking the power of decentralization for mainstream users, merchants, and developers.

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